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WEATHER AND THE COTTON BOLL WEEVIL

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The cotton boll weevil is of Mexican origin and first appeared in the United States in 1892, near Brownsville, Tex., on the Rio Grande River. It spread slowly northward and eastward in the succeeding years, and by 1903 had reached the Louisiana border, while three years thereafter southeastern Oklahoma and extreme southwestern Arkansas were invaded. Thence the spread was irregular from year to year, depending largely on weather conditions. In 1916 southwestern Tennessee and the greater part of Georgia had been invaded, and by 1922 practically the entire Cotton Belt had been overrun.

In a general way, the weather influence on the activities and consequent damage by the weevil was apparent soon after their appearance in this country. As early as 1906 Mr. W. D. Hunter, in charge of cotton boll weevil investigations, of the Bureau of Entomology, recognized the dominating weather influence and the consequent importance of weather as a natural control. The following extracts are taken from a report by him, published in the Yearbook of the Department of Agriculture for that year, pages 313–324:

* * * In general, the drier and freer from timber the less is the damage by the weevil. The reasons for this are that dryness increases the death rate of immature stages in the fallen squares enormously in summer, and the absence of the protection afforded by timber contributes equally to a decrease in the number of adults in the winter. When the foregoing conditions are combined with low winter temperatures, as happens in northwestern Texas, there is a total of conditions most disastrous for the weevil. The reverse of these conditions is found in the timbered valleys of eastern Texas and Louisiana, where the precipitation is much heavier. * * *

For a long time it has been recognized that the most important single factor in assisting in the production of a cotton crop in a weevil-infested region is dryness during the growing season. An excellent illustration of this is furnished by the condition in Victoria County, Tex., during the spring of 1906. The crop of that year in Victoria County is much the largest ever produced, although the acreage probably was not as large as has been planted in other seasons. The exact records regarding production are not available at this time, but a very conservative estimate of the crop is 13,000 bales. From the accompanying table (not reproduced) it will be seen that May and June were abnormally dry months; in fact, the total precipitation for April, May, and June (4.19 inches) was less than half of the mean total for these months for the five preceding years (9.28 inches). There can be no error in estimating the effect of dryness in this case, on account of the number of weevils present. In fact, far more than the usual number of hibernating weevils appeared in the fields of Victoria County up to the end of April. In one instance, a total number of about 1,500 per acre was shown to have come to a certain field. Of course, due allowance must be made for the effect of the work of parasites and the ant *Solenopsis geminata*, referred to elsewhere. However, the dryness rather interfered with the work of the ant and certainly did not facilitate greatly the work of the parasites. Dryness, therefore, must be considered as the controlling factor.

The importance of the weather as a natural control of the boll weevil was observed also by officials of the Weather Bureau engaged in weather and crop reporting work very soon after infestation in this country. Throughout the period of their menacing presence the Bureau in its weekly weather and crop reports has, from year to year, featured this phase of the problem of cotton growing, by indicating in its summaries whether the prevailing weather had been favorable or unfavorable for weevil activity; also the probable effect of low winter temperatures on those in hibernation, based on a general broad knowledge of the weather-weevil relation.

There are three distinct periods of weather influence: (1) The prevailing conditions during the concurrent year, or the growing season for which weevil damage is considered; (2) The weather during the winter immediately preceding, primarily as to low temperatures, and (3) That for the preceding summer as influencing the number of weevils going into hibernation. In the first and third cases moisture is much the more important, and in the second low temperatures as related to mortality of the insects in hibernation. These three distinct periods of weevil influence are discussed by the Secretary of Agriculture in his report for 1927, published in the Yearbook of the Department of Agriculture for that year, page 57. In commenting on the weevil damage in 1927, he states:

Continuation of general drought conditions in the Cotton Belt in 1926 reduced damage by the cotton boll weevil during that year. However, large amounts of poison were used on cotton, primarily for the leafworm, which covered much of the territory west of the Mississippi River, with lighter injury in parts of Mississippi and Alabama. While this poison helped to destroy the weevils in the areas treated, the absence of rain during the latter months of the season was probably more important in effecting a large degree of natural control.

As a result, the insect entered hibernation in greatly reduced numbers in most of the Cotton Belt. Owing, however, to the fairly mild character of the winter of 1926–27, the percentage of weevil emergence in the spring was higher than for some years. The fairly abundant holdover of weevils, coupled with climatic conditions favorable to the insect during the succeeding months, resulted in boll weevil damage to cotton during 1927 considerably more extensive than had been experienced for several years.

Data used.—In the May, 1928, issue of Crops and Markets, a publication of the Bureau of Agricultural Economics of the Department of Agriculture, there was included a table, showing, for each State of the Cotton Belt, the estimated percentage reduction of cotton from a full yield per acre, occasioned by boll-weevil damage, for the period 1909–1927. In 1909, however, only two States had been overrun by the weevil, and even as late as 1918 a small portion of Georgia had not been affected. Therefore, the number of years available for study is limited, and the period of weevil infestation in a few States too short to afford sufficient data to include them in this survey, but all the more important cotton States, except the Carolinas and Tennessee, have been included. The number of years used for the several States are as follows: Texas, Louisiana, and Mississippi, 15; Alabama, 12; and Georgia, Arkansas, and Oklahoma, 10 each.

Weevil damage for so large an area as the Cotton Belt of this country can not be accurately determined by direct observational methods, but at the same time the data used are the best available as to weevil activity, while the uniformity of agreement between the prevailing weather and estimated damage for the several States, as shown by this study, strengthens the belief that the figures are substantially correct. There is no question as to the accuracy of the weather data, as they are based on direct instrumental observations. Again, the period is rather short for unquestioned faith in the significance of the mathematical results obtained for individual States, but at the same time the total years of observation for the seven States afford 87 separate determinations, with a remarkable uniformity shown in the weather-weevil relationship throughout the series.

The weather data used are given in Table 1. They include (*a*) relative humidity, concurrent year; (*b*) number of days with rainfall, concurrent year; (*c*) number of cloudy days, concurrent year; (*d*) rainfall, concurrent year; (*e*) lowest winter temperature, preceding winter; (*f*) relative humidity, preceding year; (*g*) percentage of possible sunshine, preceding year; (*h*) number of days maximum temperature 90° or higher, preceding summer; and (*i*) rainfall, preceding year. The numerals at the heads of the several columns indicate the period of the seasons used, as stated in a footnote. There is also shown in this table the computed weevil damage from the weather data, in percentage reduction of cotton yield ($\overline{X}$), and the estimated reduction reported by the Department of Agriculture (X). The last line shows for each State the correlation coefficient between each weather phase and the percentage of weevil reduction in yield (column X).

The number of days with rainfall, the number of cloudy days, and the total rainfall, for both the concurrent and preceding summers, are based on the records of all Weather Bureau stations, first-order and cooperative, for the respective States, a total of more than 600 stations. The relative humidity, the lowest winter temperatures, the percentage of possible sunshine, and the number of days with maximum temperature 90° or higher, represent the averages for all first-order stations within, or on the border of, the respective States. For Texas sunshine data are not available at a number of stations, and, consequently, the approximate complement of this, or the percentage of cloudiness during the daylight hours, was substituted for sunshine data, which gives a positive correlation with weevil damage for this phase in that State, as against a negative one for the other States where sunshine data were used.

The relative humidity represents the mean for the 7 p. m. observations up to and including 1917, during which time only two relative humidity observations were made daily, at 7 a. m. and 7 p. m., local time. Beginning with 1918, relative humidity observations were made at noon, in addition to the above, and from that year to 1927, inclusive, the mean of the noon and p. m. data was used. The early morning observations were not included, as it was found that records were relatively more important during the warm period of the day when readings are normally lower. The number of days with rainfall include all days on which 0.01 inch or more of rain occurred.

Only the more important weather data were used for each State, determined by straight correlations between the individual phases and weevil damage, and the correlation of the several weather phases among themselves. (See Statistical Correlations of Weather Influence on Crop Yields, by J. B. Kincer and W. A. Mattice, MONTHLY WEATHER REVIEW, February, 1928.) In all cases the best results were obtained by including one or more weather phases for each of the three periods, the concurrent summer, the preceding winter, and the preceding summer, as shown in Table 1. Moisture stands out as the most important summer factor, and the lowest temperature reached during the winter as the most important for that period.

The summer relative humidity is especially significant. The weevils deposit their eggs in the squares and young bolls, and the larvae, when hatched, feed on the interior substance of the squares and bolls. When punctured, squares, usually, and many young bolls drop to the ground in a few days, and, if it is hot with the atmosphere dry, favoring rapid evaporation of moisture from the fallen squares or young bolls, the larva may die from intense heat, or its food supply, consisting of the interior substance of the squares or bolls, be dried up; thus the per cent of emergence is reduced. On the other hand, moist, cloudy, rainy weather favors a rapid increase in numbers, from generation to generation, of which there are several, through the growing season.

Texas.—The first-order station data are the means for the stations at Abilene, Amarillo, Fort Worth, San Antonio, Taylor, and Shreveport, La. The weather data used (see Table 1) were (*a*) relative humidity, June and July, concurrent year; (*e*) lowest winter temperature, preceding winter; (*f*) relative humidity, July and August, preceding summer; and (*g*) percentage of cloudiness (substituted for sunshine in this case, as previously stated), June to September, preceding year. The multiple correlation coefficient for these and weevil damage (column X) is 0.934, as shown in equation 6, while equations 7 and 8 give the constants from which weevil damage for the several years was computed. The straight correlation between the computed damage and that reported by the department is 0.94, while the relation is graphically shown in Figure 1.

THE MULTIPLE CORRELATION FOR TEXAS

$$R^2 = \beta\, xa \cdot rax + \beta\, xe \cdot rex + \beta\, xf \cdot rfx + \beta\, xg \cdot rgx \tag{1}$$

Equation for computing the betas:

$$\left.\begin{aligned} \beta\, Xa + rae\,\beta\, xe + raf\,\beta\, xf + rag\,\beta\, xg &= +0.62 \\ rea\,\beta\, Xa + \beta\, xe + ref\,\beta\, xf + reg\,\beta\, xg &= +0.71 \\ rfa\,\beta\, Xa + rfe\,\beta\, xe + \beta\, xf + rfg\,\beta\, xg &= +0.69 \\ rga\,\beta\, Xa + rge\,\beta\, xe + rgf\,\beta\, xf + \beta\, xg &= +0.68 \end{aligned}\right\} \tag{2}$$

Solving (2) gives

$$\begin{gathered} \beta Xa = +0.424;\ \beta\ xe = +0.252; \\ \beta xf = +0.509;\ \beta\ xg = +0.118 \end{gathered} \tag{3}$$

Substituting in equation 1 gives

$$\begin{gathered} R^2 = 0.424 \times 0.62 + 0.252 \times 0.71 + 0.509 \times 0.69 \\ +0.118 \times 0.68 \end{gathered} \tag{4}$$

$$R^2 = 0.87325 \tag{5}$$

$$R = 0.934 \tag{6}$$

The regression equation:

$$\overline{X} = M_X + \beta xa \frac{\sigma x}{\sigma a}(A - M_A) + \beta xe \frac{\sigma x}{\sigma e}(E - M_E) + \beta xf \frac{\sigma x}{\sigma f}(F - M_F) + \beta xg \frac{\sigma x}{\sigma g}(G - M_G) \quad (7)$$

Where $\overline{X}$ is the computed weevil damage; X weevil damage reported by the Department of Agriculture; A, E, F, and G, the respective weather data, and M_A, M_E, M_F, and M_G, their means.

Solving (7) gives

$$\overline{X} = 0.690\,A + 0.489\,E + 0.836\,F + 0.201\,G - 77.35 \quad (8)$$

Oklahoma.—The weevil entered southeastern Oklahoma about 1905, but made very little progress for several years, with damage as late as 1910 to 1917, inclusive, averaging less than 2 per cent per year. The period covered by this study begins in 1918 and includes the 10 years from that date to 1927. The weather data used in the computations are (*d*) Table 1, number of days with rainfall, July and August, concurrent year; (*e*) lowest temperature, preceding winter; and (*f*) relative humidity, July and August, preceding year, with first-order station records for Fort Smith, Ark., and Oklahoma City. The multiple correlation coefficient between these and damage by boll weevil (column X) is 0.93. The constants from the regression (computed as for Texas) are 2.001 D + 0.653 E + 1.489 F − 93.87. The straight correlation coefficient between computed damage (column $\overline{X}$) and damage reported by the department (column X) is also 0.93, while the relation of these is shown graphically in Figure 1.

Arkansas.—This State was invaded about the same time as Oklahoma, and the period used is the same. The weather data include (*b*) number of rainy days, June and July, concurrent year; (*e*) lowest winter temperature; (*f*) relative humidity, July to September, preceding year, and (*i*) rainfall, July and August, preceding year, with first-order station records for Fort Smith, Little Rock, and Memphis, Tenn. The multiple correlation coefficient between these and weevil damage is 0.93. The constants are 1.889 B + 0.357 E + 0.820 F + 2.013 I − 87.59. The straight correlation coefficient between the computed damage and reported damage is also 0.93.

Louisiana.—Period used 15 years, 1913–1927, first-order station data Shreveport, La., and Vicksburg, Miss. Weather data used (*d*) rainfall, June and July, concurrent year; (*e*) lowest winter temperature; (*g*) percentage of sunshine, June and July, preceding year; (*i*) rainfall, July and August, preceding year. The multiple correlation between these and weevil damage is 0.90. The constants are 1.439 D + 0.289 E − 0.284 G + 0.822 I + 9.39. The straight correlation between computed damage and reported damage is 0.89.

Mississippi.—The period covers 15 years, 1913–1927, with first-order station records Memphis, Tenn., Meridian and Vicksburg, Miss. Weather data used (*a*) relative humidity, July and August, concurrent year; (*c*) number of cloudy days, April to August, concurrent year; (*d*) rainfall, June to September, concurrent year; (*e*) lowest winter temperature; (*f*) relative humidity, July and August, preceding year, with a multiple correlation of 0.96. The constants are 0.588 A + 0.352 C + 0.690 D + 0.701 E + 0.563 F − 87.90. The straight correlation between computed damage and reported damage is 0.96.

Alabama.—The weevil had practically overrun Alabama in 1916, and the period used for that State was the 12 years 1916–1927, with first-order station records for Birmingham, Montgomery, and Meridian, Miss. The data used were (*a*) relative humidity, July and August, concurrent year; (*d*) rainfall, July and August, concurrent year; (*e*) lowest winter temperature; and (*h*)

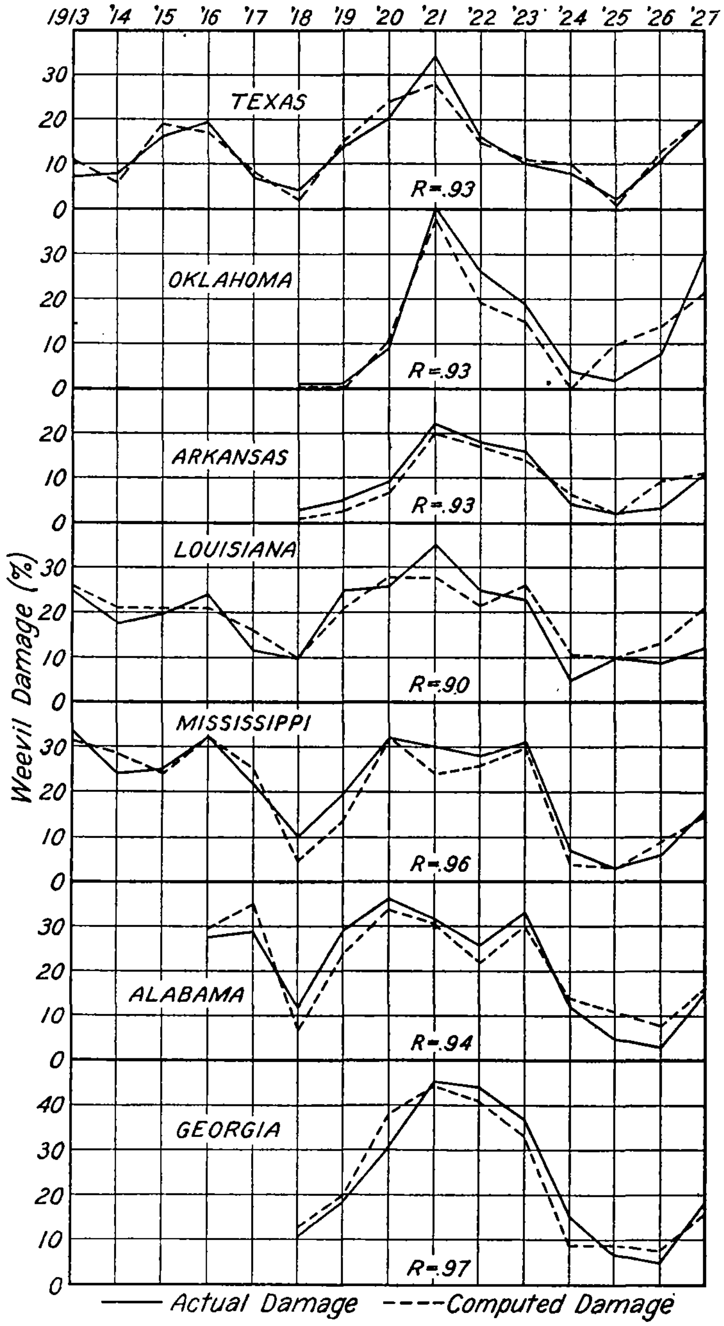

FIG. 1.—Showing graphic relation between the computed damage from weather data by cotton boll weevil for the several States shown in Table 1 (column $\overline{X}$) and the damage reported by the Department of Agriculture (column X)

number of days with temperature 90° or higher, preceding summer. The multiple correlation between these and reported weevil damage is 0.94. The constants are 1.972 A − 1.445 D + 0.605 E − 0.190 H − 86.40. The straight correlation between computed damage and reported damage is 0.94.

Georgia.—This State was invaded in 1910 and completely covered about 1917. The period used includes the 10 years from 1918 to 1927, with first-order station records for Atlanta, Augusta, Macon, and Thomasville. The data used were (*a*) relative humidity, July and August, concurrent year; (*e*) lowest winter temperature; (*g*) percentage of sunshine, July and August, preceding year; and (*i*) rainfall, July and August, preceding year. The multiple correlation coefficient between these and reported weevil damage is 0.97. The constants are $1.226\ A + 1.386\ E - 0.910\ G + 0.741\ I - 27.60$. The straight correlation between the computed yield from these constants and the reported yield (column $\overline{X}$ and X, respectively) is also 0.97.

Acknowledgment is hereby made of the valuable cooperation given in this study by Mr. W. A. Mattice, who assisted in computing the many correlations required, and by Miss G. B. Diehl, in the compilation and computation of necessary data.

TABLE 1

TEXAS

	Relative humidity, concurrent year	Number of days with rainfall, concurrent year	Number of cloudy days, concurrent year	Rainfall, inches, concurrent year	Lowest winter temperature, preceding winter	Relative humidity, preceding year	Percentage of possible sunshine, preceding year	Number of days with maximum temperature 90° or higher, preceding summer	Rainfall, inches, preceding year	Computed weevil damage from weather data	Weevil damage reported by the Department of Agriculture
	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(1)	(3)	(3)	(3)		(2)	(4)		(3)		
1913	50	13	17	6	13	48	36	93	7	11	7
1914	47	15	14	9	13	43	42	84	6	6	8
1915	50	15	13	10	18	54	40	82	9	19	16
1916	50	15	12	8	12	54	42	67	10	17	19
1917	43	10	6	5	12	50	40	95	8	8	7
1918	46	12	8	5	3	48	32	91	5	2	4
1919	62	23	19	14	15	42	35	100	5	15	14
1920	52	21	15	12	15	58	50	51	14	24	20
1921	56	16	12	10	21	56	46	71	12	28	34
1922	51	12	8	6	17	48	43	88	10	15	16
1923	50	14	8	7	16	46	38	87	6	11	10
1924	47	9	7	4	15	46	43	80	7	10	8
1925	42	13	9	6	11	44	34	87	4	1	2
1926	54	17	14	9	15	44	42	109	6	12	11
1927	52	16	13	8	19	52	43	87	9	20	20
M	50	15	12	8	14	49	40	85	8	13	13
r's	+.62	+.44	+.28	+.54	+.71	+.69	+.68	−.51	+.79	R=.93	

OKLAHOMA

	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(1)	(1)	(1)	(1)		(2)	(1)		(1)		
1918	42	10	7	5	−9	53	78	62	5	0	1
1919	58	14	8	6	4	40	79	82	5	0	1
1920	55	12	7	6	8	51	76	64	6	11	9
1921	62	19	12	10	12	58	76	49	6	38	41
1922	54	11	6	6	12	56	68	72	10	19	26
1923	54	14	5	6	10	50	73	78	6	15	19
1924	52	13	6	6	3	44	74	67	6	0	4
1925	51	14	8	6	4	49	72	70	6	10	2
1926	56	13	6	8	7	52	69	86	6	14	8
1927	58	15	11	10	4	56	58	64	8	22	31
M	54	14	8	7	6	51	72	69	6	13	14
r's	+.62	+.60	+.57	+.70	+.61	+.72	−.46	−.50	+.54	R=.93	

ARKANSAS

	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(1)	(1)	(3)	(1)		(5)	(3)		(2)		
1918	54	11	18	5	−9	64	73	40	9	1	3
1919	60	15	20	7	9	60	77	63	5	3	5
1920	60	13	20	8	14	65	71	53	6	7	9
1921	60	17	19	7	17	65	68	36	8	20	22
1922	62	14	17	7	20	67	72	71	8	17	18
1923	62	15	17	9	13	69	74	59	6	14	16
1924	56	13	17	6	7	66	71	46	6	6	4
1925	56	14	15	7	8	61	72	58	5	2	2
1926	54	14	17	6	8	65	75	86	7	9	3
1927	60	15	23	9	10	59	72	60	9	11	11
M	58	14	18	7	10	64	72	57	7	9	9
r's	+.70	+.65	+.21	+.49	+.71	+.41	−.47	−.18	+.34	R=.93	

LOUISIANA

	Relative humidity, concurrent year	Number of days with rainfall, concurrent year	Number of cloudy days, concurrent year	Rainfall, inches, concurrent year	Lowest winter temperature, preceding winter	Relative humidity, preceding year	Percentage of possible sunshine, preceding year	Number of days with maximum temperature 90° or higher, preceding summer	Rainfall, inches, preceding year	Computed weevil damage from weather data	Weevil damage reported by the Department of Agriculture
	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(4)	(1)	(4)	(1)		(4)	(1)		(2)		
1913	66	20	39	11	22	70	56	58	12	26	25
1914	66	16	28	10	20	66	66	71	12	21	18
1915	66	12	24	9	18	66	67	76	15	21	20
1916	66	22	24	12	18	66	76	59	13	21	24
1917	60	12	19	7	16	66	64	70	12	16	12
1918	55	13	22	7	3	60	68	56	11	10	10
1919	66	24	38	13	13	55	66	81	10	21	25
1920	65	22	27	13	22	66	56	49	11	28	26
1921	63	21	24	12	25	66	64	46	15	28	35
1922	67	21	26	11	26	63	68	82	10	22	25
1923	66	24	30	14	22	67	66	56	11	26	23
1924	52	10	16	4	13	66	64	46	13	11	5
1925	52	18	30	10	18	52	80	80	4	10	10
1926	60	17	25	8	15	52	68	100	9	13	9
1927	61	22	40	11	20	60	74	82	13	21	12
M	62	18	27	10	18	63	67	67	11	20	19
r's	+.78	+.65	+.28	+.78	+.63	+.43	−.36	−.31	+.33	R=.90	

MISSISSIPPI

	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(2)	(4)	(6)	(4)		(2)	(1)		(4)		
1913	66	36	29	18	23	73	62	37	18	31	33
1914	70	34	35	17	19	66	74	58	18	28	24
1915	66	28	31	17	16	70	78	64	17	24	25
1916	74	36	37	20	18	66	74	48	17	32	32
1917	70	31	31	15	13	74	60	47	20	25	22
1918	56	27	28	14	1	70	76	41	15	5	10
1919	67	34	38	16	10	56	74	60	14	14	20
1920	70	33	42	19	19	67	68	41	16	32	32
1921	64	32	26	14	23	70	72	28	19	24	30
1922	66	31	36	13	25	64	76	71	14	26	28
1923	68	36	41	19	19	66	70	43	13	30	31
1924	54	21	26	9	9	68	74	26	19	4	7
1925	57	28	21	13	15	54	80	65	9	3	3
1926	63	31	30	15	10	57	72	84	13	9	6
1927	60	32	34	15	14	63	78	62	15	15	16
M	65	31	32	16	16	66	73	52	16	20	21
r's	+.79	+.71	+.62	+.69	+.74	+.51	−.44	−.31	+.42	R=.96	

ALABAMA

	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(2)	(2)	(4)	(2)		(2)	(2)		(2)		
1916	75	25	19	20	15	65	67	63	10	30	28
1917	72	24	15	12	10	75	62	45	20	35	29
1918	56	14	12	8	7	72	62	51	12	7	12
1919	69	24	19	14	9	56	66	58	8	24	29
1920	68	23	20	12	18	69	52	37	14	34	36
1921	63	22	13	10	25	68	54	38	12	31	32
1922	62	17	10	8	25	63	66	89	10	22	26
1923	68	23	16	12	18	62	69	57	8	30	33
1924	56	13	7	6	7	68	62	28	12	14	12
1925	54	14	11	6	21	56	80	71	6	11	5
1926	64	24	18	13	10	54	68	99	6	8	3
1927	60	17	11	8	13	64	66	66	13	16	15
M	64	20	14	11	15	64	64	58	11	22	22
r's	+.70	+.59	+.45	+.46	+.37	+.38	−.55	−.42	+.40	R=.94	

GEORGIA

	a	b	c	d	e	f	g	h	i	$\overline{X}$	X
	(2)	(2)	(2)	(2)		(2)	(2)		(2)		
1918	60	19	15	9	10	72	60	51	10	13	11
1919	70	27	20	14	13	60	69	48	9	20	19
1920	68	27	22	14	17	70	57	40	14	38	31
1921	68	26	18	12	26	68	64	39	14	44	45
1922	67	22	15	8	23	68	60	72	12	41	44
1923	68	21	18	10	20	67	62	50	8	33	37
1924	62	18	12	8	8	68	64	34	10	9	15
1925	54	14	13	5	24	62	76	57	8	9	7
1926	66	25	15	12	12	54	72	93	5	8	5
1927	66	22	12	10	14	66	72	61	12	16	18
M	65	22	16	10	17	66	66	54	10	23	23
r's	+.60	+.41	+.47	+.23	+.63	+.48	−.61	−.29	+.65	R=.97	

M=Means.
r's=Correlation coefficient between weather data and weevil damage.
R=Gross, or multiple coefficient between weather data and weevil damage.
(1) June and July, combined; (2) July and August, combined; (3) June to August, inclusive; (4) June to September, inclusive; (5) July to September, inclusive; (6) April to August, inclusive.